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AN INTRODUCTION

TO THE

STUDY OF CHEMISTRY

SPECIALLY DESIGNED FOR MEDICAL AND PHARMACEUTICAL STUDENTS

BY

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PREFACE.

THIS small book has been written for the use of students commencing the study of chemistry. The endeavour of the author is to systematically introduce beginners to the study of the science, and to explain and render clear the elementary facts and laws connected with the subject. A special feature in the work is the space devoted to the construction of chemical formulæ, and the representation of reactions by means of chemical equations, portions of the subject which generally offer such serious impediments to the progress of the young student.

It is barely necessary to state, considering the small size of the book, that it is not a manual, nor even a manualette, of chemistry; nor is it in any way concerned with the history of the elements and their compounds. The book is intended for study previous to working at a manual of chemistry, and the author trusts that the explanations of the elementary principles of the science, the exposition

of its laws, the *modus operandi* in the construction of chemical formulæ at will, and the writing out of equations, will remove many difficulties from the path of the young student, and prevent the feeling of helplessness and despair so often experienced on first opening a large text-book of chemistry.

It may be mentioned here that the matter contained in the last twelve pages will be found more especially useful to students when they have made some progress in the study, both theoretical and practical, of chemistry.

A. P. L.

London, February, 1880.

PREFACE TO THE SECOND EDITION.

THE principal addition to this, the Second Edition, consists in a series of analytical tables for the detection of a single metal and single acid, as is required for the Practical Chemistry Examination of the Royal College of Physicians, and for the Minor Examination of the Pharmaceutical Society. These tables are placed at the end of the book.

A. P. L.

London, February, 1885.

INTRODUCTION

TO THE

STUDY OF CHEMISTRY.

MATTER.

In order to commence the Study of Chemistry clearly and definitely, it is absolutely necessary that the student should understand what matter is, the different forms in which it exists, and the laws which cause the existence of these different forms of matter.

The Three Forms of Matter.—Matter is that which is evident to the senses, and it exists in three forms, viz., the *solid*, *liquid*, and *gaseous*: any one of these forms of matter can be converted into either of the other two: thus by melting *solid* ice it becomes *liquid* water, and by boiling the liquid water *gaseous* steam is produced. The particles of all bodies are under the influences of two forces, an attractive force and a repulsive force; and according to the distribution of these forces of attraction and repulsion the different forms of

matter result (it will be shortly seen that the repulsive force, which the particles of matter have for one another, is identical with heat).

If one of the forces is in excess of the other, one of the two extreme forms of matter (the solid or the gaseous) results; if the two forces are equally balanced, the intermediate form of matter (the liquid) is the result.

Thus in all **solids** the force of attraction of the particles for one another is greater than the force of repulsion. The peculiarity of the solid form of matter is that the relative positions of its particles cannot be changed without the expenditure of more or less force; solids therefore tend to retain whatever form they may happen to possess.

In **liquids** the attractive and repulsive forces of the particles are equally balanced. The distinctive peculiarity of the liquid state is that the particles readily glide over one another and assume the shape of the vessel containing the liquid.

In **gases** the repulsive force of the particles is greater than the attractive force. The distinctive character of the gaseous state is that the particles are continually undergoing a struggle to occupy a larger space. It will now be easy for the student to understand why a gas can be compressed by additional pressure, and expanded by partial removal of pressure; the compression of a gas being brought about by the mechanical force employed overcoming the repulsive force of its particles: and the expansion of a gas being caused by the repulsive force of

the particles for one another coming into play when the pressure is removed.

It must not be supposed that the particles of any one of these forms of matter are in absolute contact with one another, although such is a common opinion with regard to solids and liquids. That solids are in reality porous, that the particles are not absolutely close together, is proved by hammering or powerfully pressing them, when they will be found to occupy a smaller bulk than they did previous to their being submitted to pressure: and again is shown by what is technically called the "sweating" of iron in the Bramah hydraulic press, where water under powerful pressure actually forces its way through the pores of a stout iron cylinder, although to the eye the iron appears perfectly compact and homogeneous. That liquids are porous is best proved by mixing certain liquids together, when a contraction in bulk takes place. If spirit and water be mixed together, a diminution in volume occurs, the particles getting closer together than they formerly were, due to a molecular combination of the spirit with the water; thus, in making the Proof Spirit of the British Pharmacopœia, 100 fluid ounces of rectified spirit are mixed with 60 fluid ounces of water, producing only 156 fluid ounces of proof spirit: a contraction of about 2½ per cent. having taken place.

The student having now become acquainted with the different forms of matter, the next thing for him to understand is how and under what conditions any one form of matter is capable of being converted

into another. Heat is the agent necessary for the transformation of one form of matter into another, and it is the addition or abstraction of heat which brings about the change of state in any form of matter. If a piece of roll sulphur (representing the solid form of matter) be heated in a test-tube or flask, it will first melt to a syrupy fluid (representing the liquid form of matter), and this on further heating will boil away, forming a heavy vapour of a reddish-brown colour (representing the gaseous form of matter): heat is therefore the agent which has converted the solid into a liquid, and the liquid into a gas or vapour. Now, if part of the heat be abstracted from the sulphur vapour, it will condense to the syrupy fluid, and this on further cooling (or what is the same thing—further abstraction of heat) will solidify to a mass of solid sulphur. From these simple experiments the following general law can be deduced:—

Either the addition or abstraction of heat is necessary for the conversion of any one form of matter into another form.

Latent Heat.—This heat which is stored up in liquids and gases, and which prevents their change of state, is called *latent heat.* Latent or hidden heat is that heat which cannot be detected by the thermometer, which is doing other work than that of making itself sensible to the thermometer, viz.:—Preventing the change of state of the body in which it is stored up. Thus, on heating the piece of roll

sulphur a quantity of heat is rendered latent and converted into energy, which keeps the sulphur in the liquid form: on further heating the melted sulphur until it boils, more heat is rendered latent in order to convert the liquid sulphur into the gaseous or vaporous form. To condense the sulphur vapour to a liquid, part of the latent heat must be abstracted by bringing the vapour into contact with some cool substance, which takes away the latent heat and converts it into sensible heat: the sulphur vapour, having now lost the energy which kept it in the gaseous form, condenses to a liquid; if the latent heat of this liquid be in its turn abstracted by further cooling, the melted sulphur will solidify.

The subject of *latent heat* will be rendered more intelligible to the student by quoting an example; the conversion of ice into water will be taken. If 1 lb. of ice at 0° C. be mixed with 1 lb. of water at 79° C., 2 lbs. of water at 0° C. will be the result. In this case the heat which had raised 1 lb. of water through 79° C. has disappeared, but it is not lost; it has converted the pound of ice into a pound of water, and in doing so the heat has been rendered latent by the melting ice; it has not raised the temperature of the ice, but has changed it from the solid to the liquid state; if the water be frozen this latent heat would be given out in the form of sensible heat.

Mixtures and Chemical Compounds. — Before treating of the force known as chemical attraction, or chemical affinity as it is sometimes termed, it will be well for the student to clearly understand the

difference between a mixture of substances and a chemical compound. **A mixture** possesses all the properties of its ingredients, and these ingredients can be mixed in any proportions. **A Chemical Compound** possesses entirely different properties to those of its ingredients, and the proportion of each of its constituents is invariable. A very good example is furnished by a mixture of iron and sulphur, and by sulphide of iron, a compound of iron and sulphur. If iron filings and powdered sulphur be rubbed together, the mixture possesses all the properties of its constituents; for with a magnet the iron filings can be picked out and the sulphur left, or by treating the mixture with a liquid called bisulphide of carbon, the sulphur can be dissolved out and the iron filings left, on evaporating the bisulphide of carbon solution, the sulphur will be left. But if the iron filings and sulphur be heated in a crucible, chemical combination takes place, and a black mass of sulphide of iron is formed, which chemical compound possesses entirely different properties to its constituents; a magnet is incapable of abstracting the iron from it: bisulphide of carbon will not dissolve out the sulphur from it: on treating it with dilute sulphuric acid, a gas, possessing an offensive odour, called sulphuretted hydrogen, is evolved: neither iron nor sulphur possess the property alone of evolving this gas when treated with dilute sulphuric acid. As may be readily comprehended, a mixture of iron filings and sulphur could be made with any proportions of the constituents, but the chemical

compound sulphide of iron requires the constituents to be present in the fixed proportions of 56 parts by weight of iron to 32 parts by weight of sulphur (the student will shortly learn that these are the atomic or combining weights of iron and sulphur); if different proportions to these are used, then a mixture of sulphide of iron with excess of either iron or sulphur will be the result, accordingly as excess of iron or of sulphur has been used.

Characters of Chemical Attraction.—It is necessary that the student should pay great attention to the peculiar characters by which the force of chemical attraction may be recognised, for it is by means of this force that the comparatively few elementary bodies arrange themselves into the numberless compounds of which the animal, vegetable, and mineral kingdoms are composed.

Chemical attraction is an extremely powerful force, which acts only on the smallest particles of matter, and between inappreciable distances. An example of the last-mentioned fact is obtained by powdering and rubbing together in a mortar tartaric acid and carbonate of soda; no change whatever occurs, for it is impossible, by mere mechanical force, to bring the two substances into sufficiently close contact to react on one another; but if water be now added to the mixture in the mortar, the two substances will dissolve, and in the dissolved state will come sufficiently close to one another to react, chemical action being manifested by the effervescence that takes place, due to the tartaric acid

acting on the carbonate of soda, forming tartrate of soda, and liberating carbonic acid gas.

Chemical attraction exists between the particles of dissimilar kinds of matter, and the result of chemical combination is an entire change of properties in the compound produced. For instance, a piece of iron shows no desire to unite with another piece of iron; but if the iron be heated with a dissimilar kind of matter, as sulphur, chemical combination takes place, and a new body, sulphide of iron, is formed, which possesses entirely different properties to its constituents, as has been previously explained.

A most important phenomenon, which is always the result of chemical combination, is the production of heat. It must be carefully borne in mind, that *whenever chemical action takes place heat is produced;* by remembering this, the student will be able to comprehend and explain many phenomena which will come under his notice, both while studying chemistry and while engaged in the duties of every-day life. The following are a few examples of heat produced by chemical action. If a piece of the metal potassium be thrown on to water, the potassium decomposes the water, forming hydrate of potassium and evolving part of the hydrogen of the water: the heat produced by this chemical action is sufficient to set fire to the escaping hydrogen, which burns with a violet-coloured flame (the colour being due to a trace of potassium volatilized by the heat). If a small piece of dry phosphorus be placed on a few fragments of iodine, the two substances will

immediately commence to combine and form the iodide of phosphorus, and the heat produced by this chemical combination ignites that portion of the phosphorus which has not already united with the iodine. The limelight, which is familiar to all, affords another good illustration of heat produced by chemical action; to produce the light, the oxy-hydrogen flame is made to impinge on a piece of lime, the oxygen and hydrogen in combining chemically with each other produce an intense heat, and this raises the particles of the lime upon which the flame impinges to a white heat; the particles, glowing at this white heat, emit the dazzling light. Another and a still more common example of heat produced by chemical action, is that derived from the burning of coals in our fire-grates; in this case the constituents of the coal combine chemically with the oxygen of the air, the heat resulting from this chemical action causes the coals to glow and inflames the gases escaping from the burning coal; in fact, in most cases where heat is obtained artificially, it is the result of chemical action. One last important example of heat produced by chemical action that may be quoted is that of animal heat, or that heat which maintains the temperature of the living body; the oxygen of the air that we inhale is absorbed by the blood circulating through the lungs, and is then conveyed in the blood to the various tissues of the body, where the carbon and hydrogen of the tissues become oxidized or burnt by this oxygen to carbonic acid gas and water respectively, and it is

the heat produced by this chemical action, by this oxidation, which serves to maintain the temperature of the animal body.

Having now given a general idea of the main facts and laws connected with the different forms of matter, the study of chemistry proper will be proceeded with, and the most important principles connected with it brought under the notice of the student.

ELEMENTS AND COMPOUNDS.

Chemistry is the science which enables us to resolve complex forms of matter into simpler or elementary forms, and to construct compound forms of matter from the simpler or elementary forms. The resolution of complex bodies into simpler or elementary bodies is called **analysis** (*ἀνα*, up, and *λύσις*, separation), and the construction of compounds from simpler bodies is called **synthesis** (*σύν*, together, and *θέσις*, putting).

The numberless compounds met with in the animal, vegetable, and mineral kingdoms can all be resolved or split up by analysis, or otherwise, into sixty-six simpler forms of matter, which are called the *elements*. An *element* is a body (it may be either a solid, a liquid or a gas) which hitherto has resisted all attempts to decompose it into simpler forms of matter; for example, silver and oxygen are two of the elements, and all attempts have, up to the present time, been incapable of decomposing them into simpler bodies. A *compound* is a body com-

posed of two or more elements, and which is therefore capable of being split up into them; for example, oxide of silver is a compound, for it is possible by simply heating it to resolve it into the two elements, silver and oxygen, the former being left as finely divided metal, the latter escaping as a gas.

The following is a list of the sixty-six elements arranged alphabetically; classified lists of the more important elements as they are to be learnt and remembered by the student will be given shortly.

LIST OF THE ELEMENTS.

Aluminium.	Hydrogen.*	Rhodium.
Antimony.	Iodine.*	Rubidium.
Arsenicum.	Indium.	Ruthenium.
Barium.	Iridium.	Selenium.*
Bismuth.	Iron.	Silicon.*
Boron.*	Lanthanum.	Silver.
Bromine.*	Lead.	Sodium
Cadmium.	Lithium.	Strontium.
Calcium.	Magnesium.	Sulphur.*
Carbon.*	Manganese.	Tantalum.
Cæsium.	Mercury.	Telluriun.*
Cerium.	Molybdenum.	Terbium.
Chlorine.*	Nickel.	Thallium.
Chromium.	Niobium.	Thorinum.
Cobalt.	Nitrogen.*	Tin.
Copper.	Norium.	Titanium.
Didymium.	Osmium.	Tungsten.
Erbium.	Oxygen.*	Uranium.
Fluorine.*	Palladium.	Vanadium.
Gallium.	Phosphorus.*	Yttrium.
Glucinum.	Platinum.	Zinc.
Gold.	Potassium.	Zirconium.

These sixty-six elements are divided into two classes, viz.: metals and non-metals. Fourteen non-metallic elements exist; they are distinguished

in the above list by having asterisks attached to their names.

Metals and Non-metals.—In much about the same way that all living things are divided into two great kingdoms, the animal and the vegetable, so the elements are divided into two classes, metals and non-metals; and in just the same way that no single character will distinguish every member of the animal kingdom from every member of the vegetable kingdom, in like manner no single character is sufficient to distinguish all the metals from all the non-metals; that is, the two classes gradually merge into and blend with one another, and only the far separated members of both classes possess any well marked distinguishing characters. A few of the best marked characters, and those that may be most readily recognised, are the following:—Metals possess, or can be made to possess by polishing or by powerful compression, a peculiar greyish lustre, known as *metallic lustre*, this character is well known to everyone; it is true that metals in a fine state of division, such as the *reduced iron* of the Pharmacopœia, do not possess this lustre, but if by powerful pressure or hammering, they are compressed into a mass, and this mass be polished, the metallic lustre is then developed; there are two of the common metals which do not possess the peculiar greyish lustre common to the other metals, but which are coloured, viz.:—**copper,** which is of a reddish colour, and **gold,** which is of a yellow colour. Non-metals are destitute of this peculiar lustre known

as metallic lustre; it is impossible to develop a mirror-like surface on a stick of phosphorus, or on a piece of sulphur; the only non-metallic element which possesses anything like a metallic lustre is *iodine*, which is too well known to be confounded with a metal. Metals are also good conductors of both heat and electricity, whereas non-metals are extremely bad conductors of these two forces.

Physical Conditions of the Elements.—Of all the elements, four only are gases, viz.:—*hydrogen*, *oxygen*, *nitrogen*, and *chlorine* (*fluorine* may possibly be a gaseous element, but as it has never been isolated in a state of purity, it cannot, with fairness, be included in the list of elementary gases). Two of the elements, *mercury* and *bromine*, are liquid at ordinary temperatures; the remaining elements are solids. The physical condition of any element can however be altered; thus the four elementary gases can be liquefied by subjecting them to powerful pressure and extreme cold; the feat of condensing hydrogen, oxygen, and nitrogen to liquids was accomplished, the latter part of 1877, by Cailletet and Pictet, these gases having up to that time resisted all attempts to liquefy them. The two liquid elements, mercury and bromine, can in their turn have their condition altered; thus, on boiling them, they become converted into vapours or gases, and by exposing them to sufficiently low degrees of cold they freeze or assume the solid state (for instance, mercury freezes in the Arctic regions). Most of the solid elements

undergo an alteration of state on the application of heat, for instance, the metals when heated melt or liquefy, and on the further application of an intense heat volatilize or form vapours.

SYMBOLS.

A *symbol* is a shorthand method of representing an element. The symbol of an element consists of one or two letters derived generally from the Latin name of the element (the symbols for potassium and sodium are derived from the Arabic words); when the symbol is composed of one letter only, that letter is the first one that occurs in the Latin name (*e.g.*, the symbol for hydrogen is **H**, for oxygen **O**, for nitrogen **N**, for carbon **C**; when the symbol is composed of two letters, the first letter is the first one in the Latin name, and the second is some characteristic letter in the same name (*e.g.*, the symbol for chlorine is **Cl**, for magnesium **Mg**, for platinum **Pt**). In most cases the Latin names are the same as the English, but in a few cases they are not, and these exceptions must be well learnt in order to remember the symbols derived from them; the following is a list of those elements whose Latin names differ from their English ones; the symbols derived from these Latin names are given in the third column.

English names.	Latin names.	Symbols.
Antimony	Stibium	**Sb**
Copper	Cuprum	**Cu**
Gold	Aurum	**Au**
Iron	Ferrum	**Fe**
Lead	Plumbum	**Pb**
Mercury	Hydrargyrum	**Hg**

English names.	Latin names.	Symbols.
Potassium	Kalium (Arabic name)	K
Silver	Argentum	Ag
Sodium	Natrium (Arabic name)	Na
Tin	Stannum	Sn
Tungsten	Wolfram	W

The following is a list of the more common elements with their respective symbols and atomic weights; an explanation of these atomic weights will shortly be given, but previous to reading that explanation, it will be advisable for the student to commit to memory the atomic weights of the elements given in the list. The order in which the elements are arranged in this table is in that of their atomic weights, commencing with hydrogen, which possesses the lowest; this order greatly assists the memory, as after studying the list, the student is enabled to picture mentally in what part of the list any particular element occurs, and so to gain a clue to its atomic weight.

Elements.	Symbols.	Atomic weights.
Hydrogen*	H*	1
Lithium	Li	7
Boron*	B*	11
Carbon*	C*	12
Nitrogen*	N*	14
Oxygen*	O*	16
Sodium	Na	23
Magnesium	Mg	24
Aluminium	Al	27·5
Phosphorus*	P*	31
Sulphur*	S*	32
Chlorine*	Cl*	35·5

Elements.	Symbols.	Atomic weights.
Potassium	K	39
Calcium	Ca	40
Manganese	Mn	55
Iron	Fe	56
Copper	Cu	63.5
Zinc	Zn	65
Arsenicum	As	75
Bromine*	Br*	80
Silver	Ag	108
Tin	Sn	118
Antimony	Sb	122
Iodine*	I*	127
Barium	Ba	137
Mercury	Hg	200
Lead	Pb	207
Bismuth	Bi	210

The elements to which asterisks are attached are the non-metallic elements.

The Atomic Theory.

The student having now become acquainted with the differences existing between elements and compounds, the next subject to be considered is the prevailing theory with regard to the constitution of matter.

It is a familiar fact that most solid substances can, by mechanical means, be reduced to an extremely fine powder, but the particles of the finest powder, when viewed under the microscope, are seen in the form of little masses, that is, they are still capable of further division. Now the questions which for ages have been before the minds of philosophers and

chemists are, whether matter is really infinitely divisible, or whether there is a point at which the divisibility of matter ceases? The latter idea is the prevalent one, and for the exposition and adaptation of it to the laws of chemical combination, we are indebted to our own countryman Dalton. The atomic theory, which is known as "Dalton's atomic hypothesis," regards matter as being composed of indivisible particles called **atoms** (the term **atom** is derived from the Greek word *ατομος*, indivisible); it is impossible, by any means, mechanical or otherwise, to so subdivide any body as to split it up into its constituent atoms, nor is it possible for anyone to mentally picture an atom, since it is inconsistent for the mind to conceive of anything which is incapable of further division, as the mind always invests mental images with boundaries. By assigning to each element a weight corresponding to its combining weight, Dalton was enabled to throw great light on and produce satisfactory reasons for all the observed numerical laws of chemical combination (which will shortly come under our consideration).

To fully understand the matter that follows, the definitions of the two words "atom" and "molecule" must be carefully remembered. An **atom** is the smallest proportion by weight in which an element enters into or is expelled from a chemical compound; the smallest weight of hydrogen so entering or leaving a chemical compound being taken as unity. More briefly, an **atom** may be defined as the smallest

quantity of an *element* which is capable of existing, and it is indivisible.

A **molecule** (the term molecule means a small mass) is the smallest quantity of a body (elementary or compound) which is capable of existing in the free state.

With three elements, and these three cases are the only ones, a molecule consists of one atom only, viz.:—Mercury, (**Hg**), zinc (**Zn**), and cadmium (**Cd**); the molecules of all other elements contain two or more atoms: thus the molecule of oxygen contains two atoms, and is represented as O_2; the molecule of potassium contains two atoms, and is represented as K_2; the molecule of lead contains two atoms, and is represented as Pb_2: in fact, the only elementary bodies containing more than two atoms in the molecule are **phosphorus** and **arsenicum,** the molecules of which each contain four atoms, the molecule of phosphorus is therefore represented as P_4, and that of arsenicum as As_4; **ozone,** which is a modified or condensed form of oxygen, contains three atoms in the molecule, and is represented as O_3.

Compounds are formed by the union of the atoms of different elements, and the smallest possible quantity of any compound, that is, the molecule of any compound, must contain at least two different elementary atoms. As an example of a compound, the molecule of which only contains two elementary atoms, common salt (chloride of sodium) may be taken, which possesses an atom of sodium and an atom of chlorine in the molecule, which is therefore

represented as **NaCl.** The number of atoms in the molecule of a compound is unlimited, some molecules containing a very large number, as the student will notice as he proceeds with the study of chemistry.

Atomic Weights.

Every element has it own atom peculiar in properties and weight. The atomic weights of the elements represent two things—1st, their relative weights; 2nd, their combining weights; in fact, the relative weights of atoms are expressed by their combining weights.

1st. **Consideration of the Atomic Weights of the Elements as their Relative Weights.**—It must not be supposed that the atomic weights of the elements represent any actual weights, the weights are only comparative or relative to one another: for example, if equal volumes of hydrogen and oxygen be taken at the same temperature, and under the same atmospheric pressure, it will be found that the bulk of oxygen is 16 times as heavy as the equal bulk of hydrogen; now hydrogen being the lightest element, it is convenient to take it as the unit of the scale, because its combining weight is smaller than that of any other element; but this is merely a matter of convenience; taking therefore the atomic weight of hydrogen as 1, the relative or atomic weight of oxygen will be 16; nitrogen is 14 times heavier than hydrogen, and therefore its atomic or relative weight is 14. One important thing must be considered here, and may have been noticed by the

student, and that is, that in deducing the atomic weights of hydrogen and oxygen from the relative weights of equal bulks of the gases, it is assumed that a volume of hydrogen gas contained just as many molecules as an equal volume of oxygen, when the two gases are measured at the same temperature and under the same atmospheric pressure; for, if the equal volumes of the two gases did not contain an equal number of units, then the units of the two gases could not possess the relative weights that the equal bulks of gases bear to one another. This important consideration is something more than an assumption, for it admits of experimental proof; the subject has been worked at by Avogadro and Ampere, and the following hypothesis bears their names.

Avogadro and Ampere's Hypothesis.—Equal volumes of different gases, at equal pressures and temperatures, contain equal numbers of molecules. As proof of this hypothesis, there is the fact that all gases are equally affected in volume by variation of pressure and temperature; physical agencies, such as heat and pressure, not affecting the nature of molecules, but only their distance from one another; thus the heat which is necessary to cause half a pint of oxygen to expand to one pint, also causes half a pint of hydrogen to expand to just one pint; and the pressure which is necessary to compress a pint of oxygen to half a pint, will also compress a pint of hydrogen to half a pint; now it is not conceivable that the two gases could behave in

such a similar manner, unless they contained equal numbers of molecules in equal bulks.

2nd. **Consideration of the Atomic Weights of the Elements as their Combining Weights.**—The most important fact to be remembered by the student in connection with the atomic weights of the elements is, that they represent the proportions in which the elements unite with one another to form compounds, or displace one another in compounds. Thus in the case of chloride of sodium (common salt), 23 parts by weight of sodium unite with 35.5 parts by weight of chlorine, and the two elements will only unite together in these proportions; if 35.5 grains of chlorine be brought in contact with 23 grains of sodium, the two will combine and form 58.5 grains of chloride of sodium; but if more chlorine, say 50 grains, be brought in contact with 23 grains of sodium, the 23 grains of sodium will only unite with 35.5 grains of chlorine, and 14.5 grains of chlorine (the remainder of the 50 grains) will be left in the free state; in like manner, if 35.5 grains of chlorine be brought in contact with more than 23 grains of sodium, the 35·5 grains of chlorine will only be capable of uniting with 23 grains of sodium, and the remainder will be left unattacked. (N.B.—It must not be supposed by the student that all compounds can, like chloride of sodium, be made by bringing the elements of which they are composed simply into contact with one another; practically only a few compounds are capable of being prepared in such a manner.)

It will presently be shown that two elements are capable of uniting in different proportions to form different compounds, but the student will then notice that the varying proportions in which two elements unite with one another are always expressed by simple multiples of their atomic weights.

The Laws of Chemical Combination.

The following are the three laws which regulate the combination of elements to form compounds.

1st Law.—*The same chemical compound always contains the same elements united in the same proportions.* This law declares that a chemical compound always possesses an unvarying composition. For instance, from whatever part of the globe chloride of sodium (common salt) be obtained, or by whatever method it may be manufactured, it will always be found on analysis to contain 23 parts by weight of sodium to 35.5 parts by weight of chlorine, and these proportions will never vary in the compound; again, if pure water be obtained from any source and analyzed, it will be found to contain 2 parts by weight of hydrogen, to 16 parts by weight of oxygen, and in all samples of water these proportions are invariable. This law, although a very simple one, is an extremely important one, for it confers on chemistry the dignity of an exact science.

2nd Law.—*When two elements unite together in different proportions, to form different compounds, they do so in simple multiples of each other.* Thus, let

A and **B** represent two elements, the following list then represents how these two elements might combine in different proportions to form different compounds :—

A + B, A + 2B, A + 3B, A + 4B, &c.
Or, **2A + B, 2A + 3B, 2A + 5B, 2A + 7B,** &c.
Or, **A + B, A + 3B, A + 5B,** &c.

It will be noticed that the varying combining proportions of A and B are indicated by the simple multiples 1, 2, 3, 4, &c., no halving or quartering of an elementary atom ever taking place. The student will meet with numerous examples of this law in the study of chemistry; for the present it will be sufficient to bring before his notice two illustrations of it in order to complete its explanation; the two compounds of carbon with oxygen, and the two compounds of sulphur with tin will furnish good examples. Carbon forms with oxygen two compounds; the one containing the least oxygen is called carbonic oxide (CO), and the one containing most oxygen is called carbonic acid gas (CO_2); carbonic oxide contains by weight 12 parts of carbon to 16 of oxygen, and carbonic acid gas contains 12 parts of carbon to 32, or 16 × 2, of oxygen: in this case, the simple multiples 1 and 2 represent the different proportions in which the two elements, carbon and oxygen, unite with one another. Sulphur and tin unite together to form two different compounds, one containing least sulphur, which is the lower sulphide of tin (SnS), and one containing more sulphur, which

is the higher sulphide of tin (SnS_2); the lower sulphide of tin contains by weight, 118 parts of tin to 32 parts of sulphur; the higher sulphide of tin contains 118 parts of tin to 64, or 32 × 2, parts of sulphur; in this case again, the simple multiples 1 and 2 represent the different proportions in which the two elements tin and sulphur unite with one another.

It must not be supposed that the proportions 1 and 2 are the only varying proportions in which two elements unite with one another to form different compounds; any multiples may occur, so long as those multiples are whole numbers; thus a few examples of different compounds attached to some of the members of the graphic representations previously given, may assist the student in understanding this law.

Examples.

$2A+B$...	N_2O....	Nitrous oxide.	Three of the compounds of oxygen and nitrogen.
$2A+3B$..	N_2O_3 ..	Nitrous anhydride.	
$2A+5B$..	N_2O_5 ..	Nitric anhydride.	
$A+3B$..	PCl_3..	Trichloride of phosphorus	The two compounds of phosphorus and chlorine.
$A+5B$..	PCl_5..	Pentachloride of phosphorus.	

Indivisibility of Atoms.—This second law is an extremely important one, as it adds great weight to the idea of the existence of atoms; as an atom is supposed to be indivisible, it is easy to understand why, in cases where several compounds of the same elements exist, the increase is always in some

multiple of the combining weight, there is no halving or quartering of atoms; in fact, the theory of the existence of atoms is perfectly in harmony with the law of multiple proportions that has just been explained.

3rd Law.—*The proportions in which any two elements unite with a third are the same proportions in which they unite with each other, or multiples of these proportions.* For example, 39 parts of potassium unite with 35.5 parts of chlorine to form chloride of potassium, and 39 parts of potassium unite with 127 parts of iodine to form iodide of potassium; therefore, 35.5 parts of chlorine would unite with 127 parts of iodine to form the compound of iodine with chlorine (chloride of iodine), in this case the proportions, in which the two elements, chlorine and iodine, unite with the third, potassium, are the same proportions in which they unite with each other.

Quantivalence or Atomicity.

By the quantivalence or atomicity of an element is meant its atom-fixing power, that is, the equivalent or saturating value possessed by the atom of an element, represented by the number of atoms of hydrogen to which it is equivalent.

Classification of the Commoner Elements according to their Quantivalences.

Univalents or Monads.	Bivalents or Dyads.	Trivalents or Triads.	Quadrivalents or Tetrads.	Quinquivalents or Pentads.	Sexivalents or Hexads.
Hydrogen.. ... H	Oxygen..... O	Gold..... Au	Carbon..... C	Nitrogen... N	Sulphur S
Chlorine Cl	Barium Ba	Bismuth .. Bi	Silicon Si	Phosphorus P	Chromium ...Cr
Bromine Br	Calcium ... Ca	*Nitrogen** . N	Iron Fe	Arsenicum . As	Manganese.. Mn
Iodine I	Strontium ... Sr	*Phosphorus** P	Aluminium. Al	Antimony... Sb	
Fluorine F	Magnesium . Mg	*Arsenicum** As	Tin Sn		
Potassium ... K	Zinc Zn	*Antimony** Sb	Platinum ... Pt		
Sodium Na	Cadmium ... Cd	*Boron* B	*Sulphur**... S		
Lithium Li	Copper Cu		*Chromium** Cr		
Silver Ag	Lead Pb		*Manganese** Mn		
*Nitrogen**..... N	Mercury..... Hg				
	*Sulphur** ... S				
	*Chromium** Cr				
	*Manganese** Mn				
	*Carbon**..... C				
	*Iron**..... Fe (in ferrous salts)				
	*Tin** Sn (in stannous salts)				

* See page 30.

Any dyad or bivalent element possesses twice the atom-fixing power of a monad or univalent element; one atom of the dyad oxygen is therefore capable of combining with or saturating two atoms of the monad hydrogen. *Example:* Water (H_2O) consists of two atoms of H united with one atom of O.

A triad or trivalent element possesses three times the atom-fixing power of a monad element, so that one atom of a triad will combine with, and saturate, three atoms of a monad. *Example:* Chloride of gold ($AuCl_3$) consists of one atom of the triad element gold united with three atoms of the monad element chlorine. The combination of a dyad with a triad does not at first seem so easy, but bearing in mind that a triad possesses an atom-fixing power represented by three, as compared with a dyad which possesses an atom-fixing power represented by two, evidently two atoms of a triad will unite with, and satisfy, three atoms of a dyad, for they will then both possess an equal atom-fixing power represented by six; just as two threepenny pieces are equal in value to three twopenny pieces. *Example:* Oxide of bismuth (Bi_2O_3) consists of two atoms of the triad bismuth united with three atoms of the dyad oxygen. One atom of a tetrad or quadrivalent element will combine with, and saturate, four atoms of a univalent element, or two atoms of a dyad or bivalent element. *Examples:* Perchloride of platinum ($PtCl_4$) consists of one atom of the tetrad platinum united with four atoms of the monad chlorine. Carbonic acid gas (CO_2) consists of one atom of the tetrad carbon united

with two atoms of the dyad oxygen. One atom of a pentad or quinquivalent element is capable of uniting with, and saturating, five atoms of a monad or univalent element. *Example:* The pentachloride of phosphorus (PCl_5) consists of one atom of the pentad phosphorus united with five atoms of the monad chlorine. When a pentad unites with a dyad, two atoms of the pentad will satisfy, and saturate, five atoms of the dyad, for two atoms of a pentad will possess an equal atom-fixing power to five atoms of a dyad, just as two fivepenny pieces would be equal in value to five twopenny pieces. *Example:* Phosphoric anhydride (P_2O_5) consists of two atoms of the pentad phosphorus united with five atoms of the dyad oxygen. Lastly, a hexad or sexivalent element is one which possesses six times the atom-fixing power of a monad or univalent element, three times the atom-fixing power of a dyad, and so on. *Examples:* Fluoride of chromium (CrF_6) consists of one atom of the hexad chromium united with six atoms of the monad fluorine. Chromic anhydride (CrO_3) consists of one atom of the hexad chromium united with three atoms of the dyad oxygen.

The quantivalence or atomicity of an element is represented by small dashes, or by Roman numerals placed over its symbol, thus:—

Monad or univalent	H'
Dyad or bivalent	O''
Triad or trivalent	Au'''
Tetrad or quadrivalent	Pt^{iv}
Pentad or quinquivalent	P^{v}
Hexad or sexivalent	Cr^{vi}

Graphic Representation of the Quantivalence or Atomicity of the Elements.

The quantivalence of an element may be represented graphically by fixing to its symbol *arms*, corresponding in number to its atom-fixing power. A monad is represented as possessing one arm, a dyad as possessing two arms, a triad as possessing three arms, and so on, thus:—

Monad H—

Dyad —O—

Triad..... Au

Tetrad —Pt—

Pentad —P—

Hexad... Cr

It is barely necessary to caution the student against supposing that elements actually have arms projecting from them; all that we know is that such an element as oxygen possesses twice the atom-fixing power of hydrogen, and the graphic symbols serve the purpose of showing why one atom of oxygen is capable of uniting with two atoms of

hydrogen; they represent in a manner that at once appeals to the mind of the student, how different elements are capable of exerting different atom-fixing powers. These hypothetical arms are generally spoken of, and written of, as *bonds*, but the term "bond" is open to some objection, the better and less objectionable term "affinity" will therefore be used in this book. Thus, a monad possesses one affinity, a dyad two affinities, a triad three affinities, and so on.

Change or Variation of Quantivalence.—It will be noticed in the table of the elements arranged according to quantivalence, that frequently one element is inserted in more than one column, that is, apparently possesses more than one quantivalence; an explanation of the reason why an element is capable of exerting different atom-fixing powers will now be given. It should be noticed in the table referred to, that when an element is not exerting its full quantivalence, it is distinguished by being printed in italics, and by having an asterisk attached to its name.

The commoner elements which possess varying quantivalences are,

Sulphur which acts as a *hexad*, *tetrad*, and *dyad*.
Chromium „ „ „
Manganese „ „ „

Nitrogen which acts as a *pentad*, *triad*, and *monad*.

Phosphorus which acts as a *pentad* and *triad*.
Arsenicum „ „ „
Antimony „ „ „

Carbon which acts as a *tetrad* and *dyad.*
Iron " " "
Tin " " "

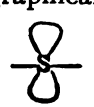
As an example of the first group, the members of which can act as hexads, tetrads, or dyads, we will take sulphur. The sulphur atom, as a hexad, is represented graphically by possessing six affinities, thus:—



Now, supposing two of the six affinities cease to exert their atom-fixing power, which can be imagined by supposing a pair of affinities to grasp one another, and so neutralize their fixing powers, the sulphur atom will then only be exerting an atom-fixing power represented by four, and will therefore be acting as a tetrad; the sulphur atom in this form is represented graphically, thus:—



Again, suppose two pairs of affinities to grasp or neutralize one another, the sulphur atom will then only have two affinities capable of exerting a uniting or combining power, and will therefore be acting as a dyad or bivalent; the sulphur atom in this condition is represented graphically, thus:—



For instance, in sulphuric anhydride ($S^{VI}O''_3$) the sulphur is exerting its full *sexivalent* atomicity; in sulphurous anhydride ($S^{IV}O''_2$) the sulphur is only exerting *quadrivalent* atomicity; in sulphuretted hydrogen (H'_2S'') the sulphur is only exerting *bivalent* atomicity.

When two affinities neutralize one another, the fact is spoken of as a pair of affinities becoming *latent* (latent meaning *hidden*); the combining power is not destroyed, but is simply rendered latent, or is hidden, for the time; for it is possible, by chemical means, to compel these pairs of latent affinities to unloose themselves, and exert their full atom-fixing power. Thus, as the student will learn hereafter, it is possible to compel the S in H_2S, in which it is acting as a dyad, to unloose a pair of its latent affinities and act as a tetrad, and in like manner, sulphur exerting the atomicity of a tetrad can be made to exert its full atom-fixing power as a hexad, by the opening of its last pair of latent affinities.

We will now consider how it is that nitrogen is capable of acting as a pentad, triad, and monad. Nitrogen, when it exerts its full atom-fixing power, is a pentad, and is therefore represented graphically as possessing five affinities, thus :—



If a pair of these affinities become latent, the nitrogen atom will then only have three affinities

left free, and will then be exerting the power of a triad; in this condition it may be represented graphically, thus:—

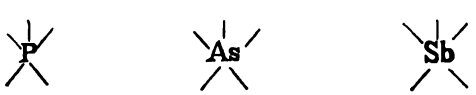


If now, another pair of affinities become latent, the nitrogen atom will then only have one affinity left free, and will then exert only the power of a monad, thus:—



For instance, in nitric anhydride ($N^{v}_{2}O^{''}_{5}$) the nitrogen is exerting *quinquivalent* atomicity; in nitrous anhydride ($N^{'''}_{2}O^{''}_{3}$) the nitrogen is only exerting *trivalent* atomicity; in nitrous oxide or laughing gas ($N^{'}_{2}O^{''}$) the nitrogen is only exerting univalent atomicity.

The remarks used in speaking of nitrogen as a pentad and a triad, apply to the three elements, phosphorus, arsenicum, and antimony, which are capable of acting as pentads and triads; the atoms of these three elements when they act as pentads are represented graphically, thus:—



When acting as triads, or only exerting trivalent atomicity, a pair of affinities become latent, and the

atoms of the three elements would then be represented graphically, thus :—

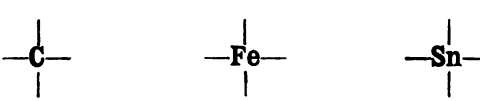


For instance, in phosphoric anhydride ($P^{V}_{2}O^{''}_{5}$) the phosphorus is exerting its full power as a *pentad* or *quinquivalent;* in phosphorus anhydride ($P^{'''}_{2}O^{''}_{3}$) the phosphorus is only exerting the power of a *triad* or *trivalent.*

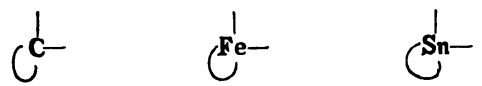
In arsenic anhydride ($As^{V}_{2}O^{''}_{5}$) the arsenicum is exerting its full power as a *pentad* or *quinquivalent;* in arsenious anhydride ($A^{'''}_{s2}O^{''}_{3}$) the arsenicum is only exerting the power of a *triad* or *trivalent.*

In pentachloride of antimony ($Sb^{V}Cl^{'}_{5}$) the antimony is exerting its full power as a *pentad* or *quinquivalent;* in the trichloride or butter of antimony ($Sb^{'''}Cl^{'}_{3}$) the antimony is only exerting the power of a *triad* or *trivalent.*

We will now briefly consider the cases of the three last-mentioned elements, carbon, iron, and tin, contained in the list of elements possessing varying quantivalences. These three elements are capable of exerting both quadrivalent and bivalent atomicities; the atoms of the three elements when acting as tetrads or quadrivalents are represented graphically, thus :—



When only acting as dyads, or only exerting bivalent atomicity, a pair of affinities become latent, and the atoms of the three elements are then represented graphically, thus:—



For instance, in carbonic acid gas ($C^{IV}O_2''$) the carbon is exerting its full atom-fixing power as a *tetrad* or *quadrivalent;* in carbonic oxide ($C''O''$) the carbon is only exerting the power of a *dyad* or *bivalent.*

In ferric chloride ($Fe_2^{IV}Cl_6'$) the iron is exerting its full power as a *tetrad* or *quadrivalent.* (N.B. The student will very likely imagine on inspection of this formula, that the iron is only acting as a triad or trivalent, since two atoms of iron are satisfied by six univalent chlorine atoms, the structure of this *apparently* abnormal formula will be explained shortly in the article on "formulæ.") In ferrous chloride ($Fe''Cl_2'$) the iron is only exerting part of its atom-fixing power, namely, that of a *dyad* or *bivalent.*

In stannic chloride ($Sn^{IV}Cl_4'$) the tin is exerting its full atom-fixing power as a *tetrad* or *quadrivalent;* in stannous chloride ($Sn''Cl_2'$) the tin is only exerting the power of a *dyad* or *bivalent.*

ACIDULOUS RADICALS.

The term **radical** signifies an unsaturated body, a body which requires something to combine with it,

and saturate it, before it is capable of existing. Acidulous radicals may be divided into two groups, *elementary* and *compound* radicals. An elementary radical consists of an element in an unsaturated condition, for example, chlorine is the acidulous radical found in all chlorides; an elementary radical always consists of one atom of the element; a molecule of chlorine is represented by the formula Cl_2, and is capable of existing in the free state, for the affinities of the two chlorine atoms are capable of uniting with, and saturating, each other, thus:—

Cl—Cl

(Graphic representation of chlorine as a molecule.)

The radical chlorine is represented by the symbol Cl, and is incapable of existing in the free state, for it is unsaturated, that is, its affinity is unoccupied, thus:—

Cl—

(Graphic representation of chlorine as a radical.)

It can now be comprehended that the radical chlorine requires something to combine with its free affinity, and saturate it.

A *compound* radical is composed of a group of elements which do not completely saturate one another, and which therefore require to be saturated by some other body, or bodies, in order to be capable of existing. By the quantivalence or atomicity of a radical is meant its degree of unsaturation, thus, a univalent radical would require one atom of a uni-

valent element to combine with and saturate it; a bivalent radical would require two atoms of a univalent element to saturate it, a trivalent radical would require three atoms of a univalent element, and so on.

We will now take a few examples, and show by graphic representations, that it is the degree of unsaturation of a radical (simple or compound) which determines its quantivalence or atom-fixing power. 1. As examples of univalent acidulous radicals we will select the radicals of—

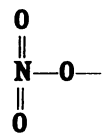
Chlorides	Cl'.
Nitrates	NO_3'.
Nitrites	NO_2'.
Cyanides	CN'.

The radical of chlorides (Cl) is the atom of the element chlorine, which, being a univalent element, has therefore a combining power represented by one.

Cl—

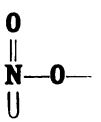
(Graphic representation of the radical of chlorides.)

The radical of nitrates ($N^{v}O_3''$) consists of three bivalent oxygen atoms united with one quinquivalent nitrogen atom, the five affinities of the nitrogen atom would therefore be capable of combining with five out of the six affinities of the three oxygen atoms, leaving one affinity unsaturated, and therefore constituting the radical a univalent one.



(Graphic representation of the radical of nitrates.)

In the radical of nitrites ($N'''O_2''$) the nitrogen is only exerting trivalent atomicity (a pair of its affinities being latent), and is united with two bivalent oxygen atoms, the three free affinities of the nitrogen atom will therefore saturate three out of the four affinities of the two oxygen atoms, leaving one affinity unsaturated, and therefore constituting the radical a univalent one.



(Graphic representation of the radical of nitrites.)

In the radical of cyanides ($C^{IV}N^{V}$) an atom of the quadrivalent element carbon is united with an atom of the quinquivalent element nitrogen; the four affinities of the carbon atom will therefore combine with four out of the five affinities of the nitrogen atom, leaving one affinity unsaturated, and so constituting the radical a univalent one.



(Graphic representation of the radical of cyanides.)

2. As examples of bivalent acidulous radicals, we will take the radicals of

Oxides..... O''.
Sulphides S''.
Sulphates..... SO_4''.

The radical of oxides (O'') is the atom of the element oxygen, which, being a bivalent element, has a combining power represented by two.



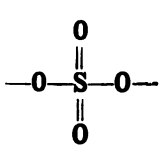
(Graphic representation of the radical of oxides.)

In all sulphides the sulphur (S'') as a radical is only exerting bivalent atomicity, two pairs of affinities of the sexivalent sulphur atom being latent.



(Graphic representation of the radical of sulphides.)

In the radical of sulphates ($S^{VI}O_4''$) one atom of sulphur, which is exerting its full sexivalent atomicity, is united with four atoms of the bivalent oxygen, the six affinities of the sulphur atom will satisfy, or combine with, six out of the eight affinities of the four oxygen atoms, leaving two affinities unsaturated, and therefore constituting the radical a bivalent one.

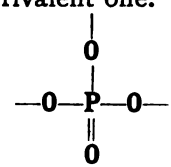


(Graphic representation of the radical of sulphates.)

3. As examples of trivalent acidulous radicals, we will take the radicals of

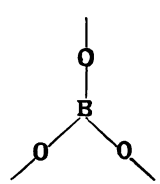
Phosphates..... PO_4'''.
Borates BO_3'''.

The radical of phosphates ($P^{v}O_4''$) is composed of one quinquivalent phosphorus atom united with four bivalent oxygen atoms, the five affinities of the phosphorus atom will satisfy, or combine with, five out of the eight affinities of the four oxygen atoms, leaving three affinities unsaturated, and therefore constituting the radical a trivalent one.



(Graphic representation of the radical of phosphates.)

The radical of borates ($B'''O_3''$) is composed of one atom of the trivalent element boron united with three bivalent oxygen atoms, the three affinities of the boron atom will satisfy, or combine with, three out of the six affinities of the three oxygen atoms, leaving three affinities unsaturated, and therefore constituting the radical a trivalent one.



(Graphic representation of the radical of borates).

These examples will be quite sufficient to enable the student to comprehend that the quantivalence of a radical is represented by the extent to which it is unsaturated, and the graphic representations will teach *why* a certain radical possesses a certain quantivalence; graphic representations of the more complex acidulous radicals (*e.g.*, of acetates $C_2H_3O_2$, and of tartrates, $C_4H_4O_6$) have not been given, as they are too complex for an elementary work, and moreover would be of no assistance at present to the student in that part of the subject which we have under our consideration.

We will now give a list of the more important acidulous radicals arranged in groups according to their quantivalence.

Univalent Acidulous Radicals.

Name.	Formula.
Radical of Chlorides	Cl.
„ Iodides	I.
„ Bromides	Br.
„ Fluorides	F.
„ Cyanides	CN or Cy.
„ Hydrates	HO.
„ Hypochlorites	ClO.
„ Nitrites	NO_2.
„ Nitrates	NO_3.
„ Chlorates	ClO_3
„ Iodates	IO_3.
„ Bromates	BrO_3.
„ Acetates	$C_2H_3O_2$.

Bivalent Acidulous Radicals.

Name.	Formula.
Radical of Oxides	O.
„ Sulphides	S.
„ Sulphites	SO_3.
„ Sulphates	SO_4.
„ Chromates	CrO_4.
„ Carbonates	CO_3.
„ Oxalates	C_2O_4.
„ Tartrates	$C_4H_4O_6$.

Trivalent Acidulous Radicals.

Radical of Borates	BO_3.
„ Arsenites	AsO_3.
„ Arseniates	AsO_4.
„ Phosphates	PO_4.
„ Citrates	$C_6H_5O_7$.

Quadrivalent Acidulous Radicals.

Radical of Silicates	SiO_4.
„ Ferrocyadines	FeC_6N_6 or $FeCy_6$.

Sexivalent Acidulous Radical.

Radical of Ferricyanides ... $Fe_2C_{12}N_{12}$ or Fe_2Cy_{12}.

The formulæ of these acid radicals, and their atomicities, together with the symbols of the elements and their atomicities (previously given), must be thoroughly committed to memory; the student will then be able to easily construct a formula, and knowing how to construct formulæ, the representa-

tion of chemical decompositions by means of equations is but another step forward. Before dealing with the construction of formulæ and equations, it will be as well, at this part of the work, to introduce to the notice of the student three most important classes of bodies, viz.:—**Acids, bases,** and **salts.**

Acids are bodies which always contain hydrogen, which hydrogen is capable of being partially or entirely displaced by a metal to form a salt, in fact, the combination of any one of the acidulous radicals with its equivalent quantity of hydrogen forms an acid. Acids which contain one atom of displaceable hydrogen are called *monobasic;* those containing two atoms of displaceable hydrogen, *dibasic;* those containing three atoms of displaceable hydrogen, *tribasic* and so on. Thus, nitric acid (HNO_3), which is composed of the univalent nitric radical, united with one atom of hydrogen, is an example of a *monobasic acid;* sulphuric acid ($H'_2SO''_4$), which is composed of the bivalent sulphuric radical united with two atoms of hydrogen, is an example of a *dibasic acid;* and phosphoric acid ($H'_3PO'''_4$), which is composed of the trivalent phosphoric radical united with three atoms of hydrogen, is an example of a *tribasic acid.* It should be carefully remembered that when the term "acid" is applied to a body destitute of hydrogen, the term is erroneously employed; for example, the so-called arsenious acid (As_2O_3) of the British Pharmacopœia cannot be an acid, for it contains no hydrogen, it is the anhydride of arsenious acid, an anhydride being derived from an acid by the abstraction of the ele-

ments of water. Two distinguishing characters possessed by most acids are, a sour taste, and the property of turning blue litmus paper red.

Bases are bodies which are capable of combining with acids, and destroying their peculiar properties; bases generally possess a caustic or alkaline taste, and have the property of turning red litmus paper blue. Bases may be divided into three classes:—

(I.) *Oxides*, of which lime or oxide of calcium (CaO), and magnesia or oxide of magnesium (MgO) may be mentioned as examples.

(II.) *Hydrates*, of which caustic potash or hydrate of potassium (KHO) and slaked lime or hydrate of calcium (Ca2HO) may be mentioned as examples.

(III.) A small class of bodies, of which the best known member, ammonia gas (NH_3), may be mentioned as a typical example.

Salts are the compounds resulting from the action of a base on an acid; an *acid salt* is obtained by the partial neutralization of an acid by a base, so that its properties are partly those of an acid, and partly those of a salt; some examples of acid salts will shortly be given.

Formulæ.

A *formula* is a representation of the composition of a body by means of symbols, which may be regarded as chemical shorthand; it consists of a grouping of the symbols of the elements composing the body, with numbers attached to these symbols, indicating the proportions in which the elements

occur in the body; when no number is attached to the symbol of an element, the number one is understood. We will now show by a few examples how to construct the formulæ of acids and salts.

An *acid* is simply a compound of an acidulous radical with hydrogen. Hydrogen being a univalent element, a univalent acidulous radical will unite with, and be saturated by, one atom of hydrogen; thus—

$H'Cl'$ is the formula of hydrochloric acid.
$H'NO_3'$ „ nitric „
$H'C_2H_3O_2'$ „ acetic „

A bivalent acidulous radical will require two atoms of the univalent hydrogen to saturate it; thus—

$H_2'SO_4''$ is the formula of sulphuric acid.
$H_2'C_2O_4''$ „ oxalic „
$H_2'C_4H_4O_6''$ „ tartaric „

A trivalent acidulous radical will, in its turn, require three atoms of hydrogen to saturate it, and form an acid; thus—

$H_3'BO_3'''$ is the formula of boracic acid.
$H_3'PO_4'''$ „ phosphoric acid.
$H_3'C_6H_5O_7'''$ „ citric „

A quadrivalent acidulous radical will require four atoms of hydrogen to saturate it, and form an acid; thus—

$H_4'SiO_4^{IV}$ is the formula of silicic acid.
$H_4FeC_6N_6^{IV}$ „ hydroferrocyanic acid.

The student can therefore construct the formula of any acid by remembering the formula and quantivalence of the acidulous radical of that acid, and then uniting the radical with its equivalent number of hydrogen atoms.

The construction of the formulæ of salts is as easy as that of acids, though some of them may appear, at first, more complex. We will first consider the formulæ of salts containing univalent acidulous radicals.

Chloride of sodium is formed by the union of the univalent element sodium with the univalent radical chlorine, its formula is therefore

$$Na'Cl'.$$

In the case of chloride of barium, two equivalents of the univalent radical chlorine will be required to satisfy the bivalent metal barium, the formula is therefore

$$Ba''Cl'_2.$$

Nitrate of bismuth will require three equivalents of the univalent nitric radical to satisfy one equivalent of the trivalent metal bismuth, its formula is therefore

$$Bi'''3NO'_3.$$

Chloride of platinum will require four equivalents of the univalent radical chlorine to satisfy one equivalent of the quadrivalent element platinum, its formula is therefore

$$Pt^{iv}\ Cl'_4.$$

We will next take a few examples of the formulæ of salts containing bivalent acidulous radicals.

Sulphate of potassium is composed of the univalent metal potassium united with the bivalent sulphuric radical; two equivalents of the former will, therefore, be required to satisfy one of the latter, so that the formula is

$$K'_2SO''_4.$$

Carbonate of calcium consists of the bivalent metal calcium united with the bivalent carbonic radical; one equivalent of each will, therefore, satisfy one another, so that its formula is

$$Ca''CO''_3.$$

Oxide of bismuth consists of the trivalent metal bismuth united with the bivalent element oxygen; now, two atoms of the trivalent element bismuth will combine with, and be saturated by three atoms of the bivalent element oxygen, for two atoms of a trivalent element and three of a bivalent one will both have an equal atom-fixing power, represented by six; the formula of oxide of bismuth is therefore

$$Bi_2'''O''_3.$$

Oxide of silicon is composed of the quadrivalent silicon united with the bivalent oxygen; one atom of silicon will, therefore, combine with two atoms of oxygen, so that the formula is

$$Si^{iv}\ O''_2.$$

Phosphoric anhydride (the higher oxide of phos-

phorus) is composed of the quinquivalent phosphorus united with the bivalent oxygen; now, for a quinquivalent and a bivalent to balance one another, two atoms of the former must be united with five of the latter, for they will then both have an equal atom-fixing power represented by ten; the formula is therefore

$$P'_2O''_5.$$

We will now practise the construction of the formulæ of salts containing trivalent acidulous radicals.

The formula of citrate of potassium requires the union of the univalent element potassium with the trivalent citric radical; three atoms of the former will satisfy one equivalent of the latter; the formula is therefore

$$K_3C_6H_5O_7'''.$$

The formula of phosphate of calcium requires the union of the bivalent metal calcium with the trivalent phosphoric radical; now, three equivalents of the bivalent calcium will satisfy two equivalents of the trivalent phosphoric radical, for they will then both possess an atom-fixing power represented by six; the formula is therefore

$$Ca''_32PO'''_4.$$

Citrate of bismuth, being composed of the trivalent metal bismuth united with the trivalent citric radical, an equivalent of each will form a saturated compound, the formula is therefore

$$Bi'''C_6H_5O_7'''.$$

We will, lastly, give two examples of the formulæ of salts containing quadrivalent acidulous radicals.

The formula of ferrocyanide of potassium requires the union of the univalent metal potassium with the quadrivalent radical of ferrocyanides; evidently, four equivalents of the former will satisfy one of the latter; the formula is therefore

$$K'_4FeCy_6^{IV}.$$

Silicate of calcium is composed of the bivalent metal calcium united with the quadrivalent silicic radical; two equivalents of the former will, therefore, satisfy one of the latter; the formula is

$$Ca''_2SiO_4^{IV}.$$

The student will find it good practice to write out the formulæ of the following salts, and have the results looked over by a teacher, or some other competent person.

Iodide of Potassium	Sulphide of Bismuth.
Bromide of Magnesium.	Sulphite of Zinc.
Acetate of Copper.	Oxalate of Bismuth.
Chlorate of Calcium.	Borate of Sodium.
Hydrate of Bismuth.	Phosphate of Lead.
Cyanide of Lead.	Citrate of Magnesium.
Tartrate of Silver.	Silicate of Potassium.
Carbonate of Sodium.	Ferrocyanide of Zinc.
Oxalate of Calcium.	Ferricyanide of Lead.

Formulæ of the Elements.

The formulæ of the elements can easily be remembered; with six exceptions, elements contain

two atoms in the molecule; thus, the formula of hydrogen is H_2: this may be represented graphically thus,

H—H

showing the affinity (bond) of the one hydrogen atom uniting with the affinity of the other hydrogen atom, and so producing a saturated body or molecule.

The formula of oxygen is O_2, which may be represented graphically by putting the two affinities of the one oxygen atom as uniting with and saturating the two affinities of the other oxygen atom, thus

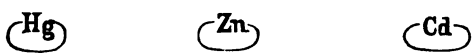
O=O

The six exceptions are mercury, zinc, cadmium (which only contain one atom in the molecule), phosphorus, arsenicum (which contain four atoms in the molecule), and a modified or condensed form of oxygen called ozone (which contains three atoms in the molecule).

The formula of	Mercury	is therefore	Hg	
„ „	Zinc	„	Zn	
„ „	Cadmium	„	Cd	
„ „	Phosphorus	„	P_4	
„ „	Arsenicum	„	As_4	
„ „	Ozone	„	O_3	

In the cases of mercury, zinc, and cadmium, the student will no doubt wonder how an atom can exist as a molecule, that is, as a fully saturated body; these three elements are dyads, and it is therefore quite conceivable that the atom of a dyad element

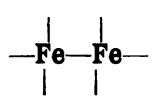
might exist singly in the free state, its two affinities satisfying each other; this may be represented graphically thus :—



APPARENTLY ABNORMAL FORMULÆ.

Before proceeding to the study of the drawing up of equations it will be as well to remove an obstacle from the student's path, by explaining the constitution of those few bodies, the formulæ of which are apparently abnormal, and which at first sight seem to disagree with the remarks just made on the construction of formulæ.

To give an illustration of what is meant, we will take as an example "perchloride of iron" (ferric chloride). Iron, as it exists in ferric salts, will be found classed among the quadrivalent elements or tetrads. Now, the formula of ferric chloride is Fe_2Cl_6, in which the iron is apparently only acting as a triad. The theoretical explanation of the constitution of this formula is that an affinity of the one iron atom is joined to an affinity of the other iron atom, so that only six affinities of the two atoms are left free to combine with the chlorine. The condition of the two iron atoms in ferric chloride may be represented graphically thus :—



Now this explanation entirely depends on a know-

ledge of the fact that the formula of ferric chloride is Fe_2Cl_6, and not $FeCl_3$; the object of this article is to explain how such knowledge is obtained. Before describing the method, a brief description concerning molecular weights and the specific gravities of gases and vapours must be given.

Molecular Weights.—The molecular weight of any body (solid, liquid, or gas) is the sum of the atomic weights of the elements composing its molecule; thus the molecular weight of oxygen is 32,

$$O_2 = 16 \times 2 = 32.$$

The molecular weight of hydrochloric acid is 36·5,

$$\begin{aligned} H &= 1 \\ Cl &= 35{\cdot}5 \\ \hline & 36{\cdot}5 \end{aligned}$$

The molecular weight of nitric acid is 63,

$$\begin{aligned} H &= 1 \\ N &= 14 \\ O_3 &= 16 \times 3 = 48 \\ \hline & 63 \end{aligned}$$

The molecular weight of sulphate of potassium is 174,

$$\begin{aligned} K_2 &= 39 \times 2 = 78 \\ S &= 32 \\ O_4 &= 16 \times 4 = 64 \\ \hline & 174 \end{aligned}$$

Specific Gravities of Gases.—The specific gravity of a gas is its weight as compared with the weight

of an equal volume of hydrogen, at the same temperature and under the same atmospheric pressure, hydrogen being taken as the standard and having its specific gravity represented as unity. The molecular weight of hydrogen being 2, (H_2=1 × 2=2), and its specific gravity 1, it follows that the specific gravity of hydrogen is half its molecular weight; and this applies to all other gases, both simple and compound; viz., *the specific gravity of any gas is half its molecular weight.* The specific gravities of the elementary gases hydrogen, oxygen, nitrogen, and chlorine, will be the same as their atomic weights, for since they all contain two atoms in the molecule, their molecular weights are the double of their atomic weights. The specific gravity of any compound gas can be calculated by finding its molecular weight and halving it; thus, the specific gravity of carbonic acid gas (CO_2) is 22, of sulphuretted hydrogen (H_2S) 17, of ammonia gas (NH_3) 8·5.

Carbonic Acid Gas.

C =12
O_2=16 × 2=32
2)44 Molec. wgt.
22 Sp. gr.

Sulphuretted Hydrogen.

H_2=1 × 2= 2
S=32
2)34 Molec. wgt.
17 Sp. gr.

Ammonia Gas.

N =14
H_3=1 × 3= 3
2)17 Molec. wgt.
8·5 Sp. gr.

From what has just been stated, it is evident that the molecular weight of a gas can be easily determined by experimentally taking the specific gravity of the gas, and then doubling that specific gravity.

Now, ferric chloride on the application of heat becomes a vapour, and vapours are nothing more than gases, and therefore are subject to the laws that govern gases. Now, if the specific gravity of the vapour of ferric chloride be taken and then doubled, the molecular weight of ferric chloride is obtained, and it is then found to correspond with the molecular weight given by the formula Fe_2Cl_6, and not with that given by the formula $FeCl_3$; for example, the specific gravity of ferric chloride vapour is 162·5, this when doubled gives 325, which is the molecular weight given by the formula Fe_2Cl_6.

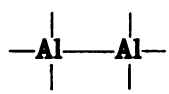
$Fe_2 = 56 \times 2 = 112$
$Cl_6 = 35{\cdot}5 \times 6 = 213{\cdot}0$
$2\)325{\cdot}0$ Molec. wgt.
$162{\cdot}5$ Sp. gr. of vapour.

If the formula of ferric chloride were $FeCl_3$, then the specific gravity of its vapour would only be 81·25.

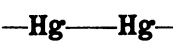
$Fe = 56$
$Cl_3 = 35{\cdot}5 \times 3 = 106{\cdot}5$
$2\)162{\cdot}5$
$81{\cdot}25$

The student must, therefore, remember to represent all ferric compounds as containing at least two atoms of iron in the molecule.

It is for a similar reason that aluminium compounds contain two atoms of aluminium linked together in a molecule, and therefore aluminium apparently acts as a triad, although it is in reality a tetrad; the constitution of the two atoms of aluminium in the chloride of aluminium (Al_2Cl_6) may be represented thus—



Another class of compounds that must be mentioned here, which possess apparently abnormal formulæ, are the mercurous salts or lower salts of mercury. In some works on chemistry mercury is stated to be a dyad in mercuric salts, and a monad in mercurous salts; for example, the formula of mercuric chloride is $HgCl_2$, and that of mercurous chloride is represented (in such books) as HgCl. Now, it is impossible to conceive of a dyad atom acting as a monad, for the one affinity cannot render itself latent; but if the formulæ of mercurous salts are represented as containing two atoms of mercury in the molecule, the explanation as to why mercury in those salts apparently acts as a monad is then rendered easy; thus, if the formula of mercurous chloride be written Hg_2Cl_2 (the double of HgCl), the constitution of the two mercury atoms may then be represented graphically thus—



where each mercury atom possesses only one free affinity, the other affinities being employed in linking

the two atoms together; the mercury in this condition is called a pseudo-monad (false monad), it is apparently only a monad, whereas in reality mercury is always a dyad. The reason why some chemists represent the formula of mercurous chloride as HgCl instead of Hg_2Cl_2 is on account of the specific gravity of its vapour being 117·75, which is half the molecular weight given by the formula HgCl—

Hg=200
Cl = 35·2
2)235·5
117·75

This apparently crushing fact is, however, easily adapted to what is doubtless the correct formula of mercurous chloride, viz., Hg_2Cl_2; for when converted into vapour, mercurous chloride no doubt dissociates into equal volumes of mercuric chloride and mercury vapours, that is, Hg_2Cl_2 splits up into $HgCl_2$ and Hg, and the mean of the specific gravities of these two substances in the state of vapour is 117·75; thus

Hg =200
Cl_2=35·5 × 2= 71
2)271
135·5 Specific gravity of $HgCl_2$ vapour.

Hg=200
2)200
100 Specific gravity of Hg vapour.

135·5 Specific gravity of $HgCl_2$ vapour.
100 „ Hg „

2)235·5

117·75, mean of the specific gravities of the vapours of $HgCl_2$ and Hg.

Empirical, Molecular, and Constitutional Formulæ.

An empirical formula is the simplest possible expression of the composition of a body; that is, it simply represents the elements composing a body, and their relative proportions to one another.

A molecular formula indicates the number of atoms in the molecule of a body, but does not show the arrangement of those atoms.

A constitutional or rational formula indicates not only the number of atoms in the molecule of a body, but also the way in which those atoms are arranged: that is, it exhibits the supposed constitution or architecture of the body.

The empirical and molecular formulæ of many bodies are identical, but in order to illustrate the meanings of the three definitions just given, we will take as an example acetic acid, which possesses distinct empirical, molecular, and constitutional formulæ. The **empirical** formula of acetic acid is

$$CH_2O,$$

which simply represents that acetic acid is composed of the three elements—carbon, hydrogen, and oxy-

gen, and that to every atom of carbon there are two atoms of hydrogen and one of oxygen.

The **molecular** formula of acetic acid is

$$C_2H_4O_2,$$

which indicates the number of atoms in the molecule, and in this case is the double of the empirical formula.

The **constitutional** or **rational formula** of acetic acid is

$$HC_2H_3O_2,$$

which indicates that one atom of hydrogen has a different arrangement to the other three hydrogen atoms, and that the remaining elements are grouped together, forming the *acetic radical*, $C_2H_3O_2$.

USES OF TERMINATIONS.

In order to speak the "chemical language" correctly, the student must become acquainted with the different terminations used in speaking of the various acids, salts, &c. For instance, he will continually have to use the terms *chlorides*, *iodides*, *sulphites*, and *sulphates*, and will often come across acids and salts, to the names of which the terminations *-ous* and *-ic* are affixed, such as *sulphurous*, *nitrous*, *sulphuric* and *nitric* acids, *ferrous*, *ferric*, *mercurous* and *mercuric* salts. We will now proceed to explain the uses of the different terminations.

Sometimes an element, in uniting with hydrogen and oxygen to form an acid, unites with different quantities of oxygen to form different acids; the

termination *-ic* is then applied to the acid containing the most oxygen, and the termination *-ous* to that containing the smaller proportion of oxygen, thus :—

H_2SO_4 is *sulphuric* acid.	H_2SO_3 is *sulphurous* acid.
HNO_3 is *nitric* acid.	HNO_2 is *nitrous* acid.
H_3AsO_4 is *arsenic* acid.	H_3AsO_3 is *arsenious* acid.
$HClO_3$ is *chloric* acid.	$HClO_2$ is *chlorous* acid.

The termination *-ate* is applied to the salts of those acids which possess the termination *-ic*, and the termination *-ite* is applied to the salts of those acids which end in *-ous*, thus :—

K_2SO_4 is *sulphate* of potassium.	K_2SO_3 is *sulphite* of potassium.
KNO_3 is *nitrate* ,,	KNO_2 is *nitrite* ,,
K_3AsO_4 is *arseniate* ,,	K_3AsO_3 is *arsenite* ,,
$KClO_3$ is *chlorate* ,,	$KClO_2$ is *chlorite* ,,

Sometimes after the naming of a group of acids, an acid has been discovered containing a greater proportion of oxygen than the one to which the ending *-ic* was applied, the prefix *per-* (abbreviation of *super*, above) is then attached to the name of the acid ending in *-ic*, to distinguish the new acid, thus :—

$HClO_4$ is *perchloric* acid.
$HClO_3$ being *chloric* acid.

On the other hand, an acid is sometimes discovered containing a smaller proportion of oxygen than the acid to which the termination *-ous* was applied, the

prefix *hypo-* (signifying *under*) is then attached to the name of the acid ending in *-ous*, to distinguish the new acid, thus :—

$HClO_2$ being chlorous acid.
HClO is *hypochlorous* acid.

When an acid contains an element for its acidulous radical, the prefix *hydro-* (abbreviation of *hydrogen*) is used, thus :—

HCl is *hydrochloric* acid.
HF is *hydrofluoric* acid.
HBr is *hydrobromic* acid.
HI is *hydriodic* acid.

The termination *-ide* is used with those salts which possess an element as their acidulous radical, thus :—

NaCl is *chloride* of sodium.
KI is *iodide* of potassium.
FeS is *sulphide* of iron.
HgO is *oxide* of mercury.

As mentioned in the article on the quantivalence of the elements, some elements are capable of exerting different combining powers; those compounds in which an element is exerting its full combining power are distinguished by having the termination *-ic* attached to their names, the termination *-ous* being attached to the names of those compounds in which the element is exerting part of its combining power only, thus :—

$P^{v}_{2}O^{''}_{5}$ is *phosphoric* anhydride.	$P^{''}_{2}{}'O^{''}_{3}$ is *phosphorous* anhydride.
$As^{v}_{2}O''$ is *arsenic* anhydride.	$As^{''}_{2}{}'O^{''}_{3}$ is *arsenious* anhydride.
$Fe^{v}_{2}Cl_{6}$ is *ferric* chloride.	$Fe''Cl_{2}$ is *ferrous* chloride.
$Sn^{iv}Cl_{4}$ is *stannic* chloride.	$Sn''Cl_{2}$ is *stannous* chloride.

Sometimes the prefixes *per-* and *proto-* or *sub-* are respectively employed instead of the terminations *-ic* and *-ous;* thus, ferric chloride is sometimes called *perchloride of iron*, and ferrous chloride the *protochloride* or *subchloride of iron;* stannic chloride is sometimes called the *perchloride* and stannous chloride the *protochloride* or *subchloride of tin.*

Chemical Equations.

The changes which occur when two or more substances act chemically upon one another are represented by placing on the left the formulæ of the substances as they exist *before* the change, connected with each other by the sign +, signifying, as in algebra, addition; on the right are formulated the substances as they exist *after* the change, connected together, as before, by the sign +, and connected with the left-hand portion by the sign of equality, $=$; such a collection of symbols is known as *a chemical equation.* A thorough knowledge of representing chemical reactions by means of equations is absolutely necessary to the student, and careful attention should be given to this subject. We will endeavour to simplify the matter by arranging it in a systematic and definite manner, commencing with reactions

that are represented by simple equations, and then proceeding, step by step, to the more difficult and complex reactions.

A large number of chemical reactions come under one or more of the four following divisions, in each of which a typical equation, constructed of letters, represents the kind of action taking place.

I.—ANALYSIS (*ἀνα* up; and *λύσις*, separation).

$$AB=A+B.$$

II.—SYNTHESIS (*σὺν*, together; and *θέσις*, putting).

$$A+B=AB.$$

III.—SINGLE DECOMPOSITION.

$$AB+C=A+BC.$$

or

$$AB+C=AC+B.$$

IV.—DOUBLE DECOMPOSITION.

$$AB+CD=AC+BD.$$

We will now take several examples of equations that come under these four heads.

1st. **Analysis.**—Typical equation AB = A + B. Under this head will come those equations which represent the splitting up of a compound body into its elements, or into less complex bodies. Thus, when mercuric oxide (red precipitate) is heated, it splits up into its elements, mercury and oxygen;

$$HgO=Hg+O.$$

This equation is not as yet quite correct, for it represents an atom of oxygen as possessing independent existence, which is an impossibility; we must, therefore, represent two molecules of mercuric oxide in the equation, which will then produce a molecule of free oxygen (O_2), which is capable of existing in the free state, thus:—

$$2HgO=2Hg+O_2.$$

The large number 2 is placed before the Hg to represent two molecules of mercury, for it is one of the three elements (Hg, Zn, Cd) which contain only one atom in the molecule.

The student must remember to represent the existence of molecules in equations, and therefore equations will frequently have to be doubled, as in the case of the one just given. In order to refer to a few more equations which come under the first head (analysis), we will take the three following examples. Oxide of silver when heated splits up into silver and oxygen,

$$2Ag_2O=2Ag_2+O_2.$$

On the right hand part of this equation, the small 2 at the base of the Ag represents two atoms, or one molecule of silver, the large 2 multiplies the whole, and therefore represents two molecules of silver.

The following equation represents the decomposition of water into its elements, which can be brought about by means of electricity:—

$$2H_2O= H_2+O_2$$

In this equation two molecules of H_2O are taken, so that the liberation of O_2, a molecule of oxygen, may be represented.

The next equation represents the manner in which chlorate of potassium ($KClO_3$) splits up, when heated, into chloride of potassium (KCl) and oxygen :—

$$2KClO_3 = 2KCl + 3O_2.$$

The equation $KClO_3 = KCl + O_3$ is not correct, for it represents the formation of a molecule and a half of oxygen, and half a molecule is incapable of a free existence. The large number 2 placed before the $KClO_3$ multiplies everything after it until it comes to the sign =, the small 3 placed under the O is therefore multiplied by the large 2.

2nd. **Synthesis.**—Typical equation $A + B = AB$. Equations of this kind represent the combination together of elements to form compounds, or the combination of simple compounds to form more complex compounds.

The following equation represents the formation of water by the union of hydrogen and oxygen :—

$$2H_2 + O_2 = 2H_2O.$$

Again, in this case, the equation $H_2 + O = H_2O$ would not be correct, as O represents an atom of oxygen, which cannot exist in the free state (we shall not trouble to explain again why, in similar equations to this, the double number is taken to prevent the representation of a free atom.)

The next equation represents the formation of

sulphide of iron (FeS) by the union of iron and sulphur (which is brought about under the influence of heat).

$$Fe_2+S_2=2FeS.$$

The following equation represents the formation of sulphurous acid gas (SO_2) by the combustion of sulphur in oxygen—

$$S_2+2O_2=2SO_2.$$

3rd. **Simple Decomposition.**—Typical equations AB+C=A+BC and AB+C=AC÷B.

The student will meet with numerous equations of this kind in his study of chemistry; the following are a few examples.

The action of zinc on hydrochloric acid (HCl), when chloride of zinc ($ZnCl_2$) is formed, and hydrogen set free—

$$Zn+2HCl=ZnCl_2+H_2.$$

The action of iron on dilute sulphuric acid (H_2SO_4), when sulphate of iron ($FeSO_4$) is formed, and hydrogen set free—

$$Fe_2+2H_2SO_4=2FeSO_4+2H_2.$$

The reduction of oxide of copper (CuO) to the metallic state by means of charcoal, which is brought about by heating the two together, when the carbon abstracts the oxygen, forming carbonic acid gas (CO_2)—

$$4CuO+C_2=2Cu_2+2CO_2.$$

In this equation it is necessary to take C_2, so as to represent a molecule of carbon, and since the two

atoms of carbon require four of oxygen to form $2CO_2$, four molecules of CuO must be taken to furnish the requisite amount of oxygen.

The formation of reduced iron (finely divided iron), which is obtained by passing hydrogen over heated ferric oxide (Fe_2O_3), when the hydrogen abstracts the oxygen, forming water and leaving the iron—

$$Fe_2O_3+3H_2=Fe_2+3H_2O.$$

In this equation it is necessary to take $3H_2$, in order to unite with the three atoms of oxygen contained i n he Fe_2O_3.

4th. **Double Decomposition.**—Typical equation AB+CD=AC+BD. Equations of this class are the most general that the student will meet with, reactions of double decomposition being of most common occurrence, more especially in connection with the tests concerned in analytical chemistry. We will take several examples of such equations.

When an oxide of a metal dissolves in an acid, as a rule, double decomposition takes place, the metal of the oxide uniting with the acid radical of the acid to form a salt, and the oxygen of the oxide uniting in its turn with the hydrogen of the acid to form water thus :—

Equation representing the action of hydrochloric acid (HCl) on oxide of zinc (ZnO)—

$$ZnO+2HCl=ZnCl_2+H_2O.$$

Equation representing the action of nitric acid (HNO_3) on oxide of copper (CuO)—

$$CuO+2HNO_3=Cu2NO_3+H_2O.$$

Equation representing the action of hydrochloric acid (HCl) on ferric oxide (Fe_2O_3)—

$$Fe_2O_3+6HCl=Fe_2Cl_6+3H_2O.$$

In writing this equation the student would have to bear in mind that ferric chloride contains six atoms of chlorine in the molecule, he would then write down 6HCl to furnish the six of chlorine, the six atoms of hydrogen will then just be sufficient to unite with the three atoms of oxygen of the Fe_2O_3 to form water.

When a hydrate of a metal dissolves in an acid, double decomposition takes place, the metal of the hydrate uniting with the acid radical of the acid to form a salt, and the radical of the hydrate (HO) at the same time uniting with the hydrogen of the acid to form water.

Equation representing the action of hydrochloric acid on caustic potash (hydrate of potassium)—

$$KHO+HCl=KCl+H_2O.$$

Equation representing the action of sulphuric acid on hydrate of calcium (Ca2HO)—

$$Ca\ HO+H_2SO_4=CaSO_4+2H_2O.$$

When solutions of two soluble salts are mixed together, and an insoluble salt (called the precipitate) is produced, the reaction is frequently one of double decomposition, thus :—

Equation representing the precipitation of sulphate of barium ($BaSO_4$) by adding sulphuric acid (H_2SO_4) to chloride of barium ($BaCl_2$)—

$$BaCl_2+H_2SO_4=BaSO_4+2HCl.$$

Equation representing the precipitation of carbonate of calcium ($CaCO_3$) by the addition of carbonate of sodium (Na_2CO_3) to chloride of calcium ($CaCl_2$)—

$$CaCl_2+Na_2CO_3=CaCO_3+2NaCl.$$

Equation representing the precipitation of mercuric iodide (HgI_2) by the addition of iodide of potassium (KI) to mercuric chloride ($HgCl_2$)—

$$HgCl_2+2KI=HgI_2+2KCl.$$

The student will now find, that with some practice he will readily be able to write out equations that may be classed in the four groups which have just been given and described.

As to whether the equation is one of splitting up (analysis), of joining together (synthesis), of single decomposition, or of double decomposition, nothing but an actual knowledge of the reaction taking place can inform the student; and in practically preparing a chemical body, or in performing a test, he will learn what kind of reaction is taking place, and so be guided as to what kind of equation to write out.

A large number of equations are more complex than those that have been given as yet, the products of decomposition being frequently more numerous than two, and sometimes more than two substances taking part in a reaction; nothing but actual practice can teach a student such reactions, but the drawing out of equations can be very much simplified by a classification, so far as that is practicable, which we

will now give, together with some hints that may prove useful on the methods of writing equations.

1. The number of atoms on the right-hand side of an equation must correspond with those on the left-hand; this, indeed, is self-evident from the position of the sign of equality (=), for one side of an equation could not be equal to the other, unless the number of atoms contained on the one side corresponded with those on the other. So that after writing an equation, the student should always verify it by seeing if the number of atoms are equal on either side.

2. Whenever a hydrate of a metal dissolves in an acid, a salt of the metal and water are produced.

Examples.

I. $KHO + HCl = KCl + H_2O$

Potassium Hydrate. Hydrochloric Acid. Potassium Chloride. Water.

II. $2KHO + H_2SO_4 = K_2SO_4 + 2H_2O$

Potassium Hydrate. Sulphuric Acid. Potassium Sulphate. Water.

III. $Ca2HO + 2HCl = CaCl_2 + 2H_2O$

Calcium Hydrate. Hydrochloric Acid. Calcium Chloride. Water.

IV. $Zn2HO + H_2SO_4 = ZnSO_4 + 2H_2O$

Zinc Hydrate Sulphuric Acid. Zinc Sulphate. Water.

V. $Fe_26HO + 6HCl = Fe_2Cl_6 + 6H_2O$

Ferric Hydrate. Hydrochloric Acid. Ferric Chloride. Water.

VI.	$Cu2HO$	+	$2HNO_3$	=	$Cu2NO_3$	+	$2H_2O$	
	Cupric Hydrate.		Nitric Acid.		Cupric Nitrate.		Water.	

In an equation of this class the formulæ of the hydrate, the acid, and the salt formed should first be written down, the latter formula will then indicate the number of molecules of hydrate and acid required; for instance, in Equation V the formula Fe_2Cl_6 shows that one molecule of Fe_26HO will be required to furnish the Fe_2, and that 6HCl will be required to furnish the Cl_6; having found these numbers, the H of the acid and the HO of the hydrate will always be in the proportion to form H_2O.

3. When an oxide of a metal dissolves in an acid, as a rule a salt of the metal and water are produced, *the only exceptions being the peroxides or higher oxides of the metals.*

Examples.

I.	BaO	+	$2HCl$	=	$BaCl_2$	+	H_2O	
	Barium Oxide.		Hydrochloric Acid.		Barium Chloride.		Water.	
II.	CaO	+	$2HCl$		$CaCl_2$	+	H_2O	
	Calcium Oxide.		Hydrochloric Acid.		Calcium Chloride.		Water.	
III.	MgO	+	H_2SO_4		$MgSO_4$	+	H_2O	
	Magnesium Oxide.		Sulphuric Acid.		Magnesium Sulphate.		Water.	
IV.	Fe_2O_3	+	$6HCl$	=	Fe_2Cl_6	+	$3H_2O$	
	Ferric Oxide.		Hydrochloric Acid.		Ferric Chloride.		Water.	

V.	Sb_2O_3	+	6HCl	=	$2SbCl_3$	+	$3H_2O$	
	Antimonious Oxide.		Hydrochloric Acid.		Antimonious Chloride.		Water.	
VI.	PbO	+	$2HNO_3$	=	$Pb2NO_3$	+	H_2O	
	Lead Oxide.		Nitric Acid.		Lead Nitrate.		Water.	
VII.	CuO	+	$2HNO_3$	=	$Cu2NO_3$	+	H_2O	
	Cupric Oxide.		Nitric Acid.		Cupric Nitrate.		Water.	

When writing an equation of this class, the formulæ of the oxide and the acid employed should be put down on the left-hand side of the equation, and the formula of the salt produced on the right-hand side, the latter will then indicate the number of molecules of acid that must be taken; thus, in the last equation of the above group, the formula $Cu2NO_3$ indicates that $2HNO_3$ must be taken to furnish the $2NO_3$, the 2H of the acid and the O of the oxide will then be in the proportion to form water.

4. When a carbonate of a metal dissolves in an acid, a salt of the metal, water, and carbonic acid gas are produced, the latter being evolved with effervescence.

Examples.

K_2CO_3	+	2HCl	=	2KCl	+	CO_2	+	H_2O
Potassium Carbonate.		Hydrochloric Acid.		Potassium Chloride.		Carbonic Acid Gas.		Water.
Na_2CO_3	+	H_2SO_4	=	Na_2SO_4	+	CO_2	+	H_2O
Sodium Carbonate.		Sulphuric Acid.		Sodium Sulphate.		Carbonic Acid Gas.		Water.

$CaCO_3$	+	$2HNO_3$	=	$Ca2NO_3$	+	CO_2	+	H_2O
Calcium Carbonate.		Nitric Acid.		Calcium Nitrate.		Carbonic Acid Gas.		Water.

It will be noticed in these equations that the radical of the carbonates (CO_3) splits up into CO_2 and O, the former escaping and the latter uniting with the H_2 of the acid to form water.

5. When a metal dissolves in *hydrochloric acid*, a chloride of the metal is always formed and hydrogen evolved.

Examples.

Zn	+	2HCl	=	$ZnCl_2$	+	H_2
Zinc.		Hydrochloric Acid.		Zinc Chloride.		Hydrogen.
Fe_2	+	4HCl	=	$2FeCl_2$	+	$2H_2$
Iron.		Hydrochloric Acid.		Ferrous Chloride.		Hydrogen.

6. When a metal dissolves in *dilute sulphuric acid*, a sulphate of the metal is always formed and hydrogen evolved.

Examples.

Zn	+	H_2SO_4	=	$ZnSO_4$	+	H_2
Zinc.		Sulphuric Acid.		Zinc Sulphate.		Hydrogen.
Fe_2	+	$2H_2SO_4$	=	$2FeSO_4$	+	$2H_2$
Iron.		Sulphuric Acid.		Ferrous Sulphate.		Hydrogen.

7. When a metal dissolves in *strong sulphuric acid*, a sulphate of the metal is formed, and *sulphurous*

acid gas (SO_2) evolved; the only common metals, whose sulphates are made by the action of strong sulphuric acid on them, are copper, mercury, and silver.

Examples.

Cu_2	+	$4H_2SO_4$	=	$2CuSO_4$	+	$2SO_2$	+	$4H_2O$
Copper.		Sulphuric Acid.		Copper Sulphate.		Sulphurous Acid Gas.		Water.
Hg	+	$2H_2SO_4$	=	$HgSO_4$	+	SO_2	+	$2H_2O$
Mercury.		Sulphuric Acid.		Mercuric Sulphate.		Sulphurous Acid Gas.		Water.
Ag_2	+	$2H_2SO_4$	=	Ag_2SO_4	+	SO_2	+	$2H_2O$
Silver.		Sulphuric Acid.		Silver. Sulphate.		Sulphurous Acid Gas.		Water.

It will be noticed in each of these three equations that *twice as much acid* is taken as is required to furnish SO_4 for the sulphate, the extra SO_4 splitting up into SO_2 and O_2, the former escaping and the latter uniting with the hydrogen of the acid to form water.

8. The ordinary metals (with the exception of antimony, tin, arsenicum, and zinc), when acted on with slightly diluted nitric acid, form metallic nitrates and evolve nitric oxide gas (N_2O_2).

Examples.

Ag_6	+	$8HNO_3$	=	$6AgNO_3$	+	N_2O_2	+	$4H_2O$
Silver.		Nitric Acid.		Silver Nitrate.		Nitric Oxide.		Water.
Cu_3	+	$8HNO_3$	=	$3Cu(NO_3)_2$	+	N_2O_2	+	$4H_2O$
Copper.		Nitric Acid.		Copper Nitrate.		Nitric Oxide.		Water.

Pb_3	+	$8HNO_3$	=	$3Pb(NO_3)_2$	+	N_2O_2	+	$4H_2O$
Lead.		Nitric Acid.		Lead Nitrate.		Nitric Oxide.		Water.
Hg_3	+	$8HNO_3$	=	$3Hg(NO_3)_2$	+	N_2O_2	+	$4H_2O$
Mercury.		Nitric Acid.		Mercuric Nitrate.		Nitric Oxide.		Water.
Bi_2	+	$8HNO_3$	=	$2Bi(NO_3)_3$	+	N_2O_2	+	$4H_2O$
Bismuth.		Nitric Acid.		Bismuth Nitrate.		Nitric Oxide.		Water.

It will be noticed in all these equations that *eight molecules of nitric acid* ($8HNO_3$) are taken; a sufficient number of atoms of the metal are then worked into the equation to unite with *six* out of the eight equivalents of the nitric radical present in the eight molecules of nitric acid, the remaining two equivalents of the nitric radical ($2NO_3$) then split up into N_2O_2 and O_4, the former escaping and the latter uniting with the hydrogen of the nitric acid to form water.

Conclusion.

The author's task being now completed, he would wish to conclude with a few words of advice to the student who is now about to commence the systematic study of the science of chemistry. An elementary knowledge of the various branches of physics is indispensable as a preliminary to the study of chemistry; their exposition in this work was, however, rendered unnecessary by the numerous books on

physics already written. For obtaining such a preliminary knowledge, students are recommended to read Professor Balfour Stewart's "Science Primer of Physics." The acquirement of chemical knowledge by the performance of experiments, and by practical work, cannot be too strongly urged.



(*a.*)

Directions for Examining a Salt or Solution Containing not More than One Metal and one Acid.

Preliminary Examination.

If a solution, evaporate a small portion to dryness and submit the dry salt to the following examination.

I. Carefully note the physical appearance of the salt, if necessary using a magnifying lens. Cautiously taste a minute fragment of the salt, being careful to afterwards spit it out.

II. Heat a small quantity in a dry tube and carefully notice if any of the following results occur.

Results.	Probably Indicative of
Salt sublimes	NH_4, Hg or As salt. Oxalic or Benzoic Acids. Sulphur.
Turns yellow and remains yellow on cooling	Pb or Bi salt.
Turns yellow, but becomes white again on cooling	Zn salt.
Brown fumes evolved.....	Nitrate.
Chars	Organic substance, such as Tartrate, Citrate, Acetate, &c.

If no charring occurs, absence of organic salts, with the exception of oxalates, is indicated.

III. Heat a small quantity in a tube with strong $H_2 SO_4$

RESULT.	INDICATIVE OF
Brown fumes evolved.....	Bromide or Nitrate.
Violet do. do.....	Iodide.
Greenish gas accompanied by explosions	Chlorate.
Colourless gas fuming in the air...	Chloride or Nitrate.
Charring	Organic matter, such as Tartrate, Citrate, &c.

The evolution of gases or odorous vapours will be dealt with in Group I for the detection of acids.

IV. Moisten a platinum wire with dil. HCl., put it in the salt and then insert in the bunsen-flame. Observe if any of the following colours are communicated to the flame.

COLOUR OF FLAME.	INDICATIVE OF
Yellow (turning the hand a livid colour)	Na.
Lasting bright Crimson flame ...	Li.
Bright crimson flame, fading shortly to yellow	Sr.
Faint reddish flame rapidly fading	Ca.
Greenish flame	Cu, Sr or Boracic Acid.
Lavender-tinted flame	K.

(*c.*)

EXAMINATION of the Solution, or of the Salt dissolved in water or in hydrochloric acid (afterwards diluted with water) for Metals.

GROUP I.

To the solution add HCl. If a p.p. occurs, see if it is soluble in excess of cold strong HCl; if it is soluble, proceed to Group II. as it will be Bi or Sb; if it is insoluble, add to the p.p. NH_4HO in excess.

SOLUBLE.	BLACKENS.	UNAFFECTED.
Ag. Confirm by KHO to orig. *Brown pp.*	Hg (-ous). Confirm by KHO to orig. *Black pp.*	Pb. Confirm by KI to orig. *Yellow p.p.*
K_2CrO_4 to orig. *Red pp.*	KI to orig. *Green pp.*	H_2SO_4 to orig. *White p.p.*

(*d.*)

GROUP II.

If no p.p. with HCl add to the same liquid H_2S water.

<table>
<tr>
<td colspan="3">BLACK P.P.
Add KHO to orig.</td>
<td colspan="2" rowspan="2">YELLOW P.P.
Collect p.p. on filter, wash, transfer to test-tube and boil with equal parts of NH_4-HO and NH_4HS.</td>
<td rowspan="3">ORANGE P.P.
Sb.
Confirm by Reinsch's Cu test w th orig.</td>
<td rowspan="3">BROWN P.P.
Sn (-ous).
Confirm by Borax and Cu Bead test with orig.</td>
</tr>
<tr>
<td>Yellow pp.
Hg (-ic).
Confirm by KI to orig.
Red pp.
Cu sublimation test with orig.</td>
<td>Blue pp.
Cu.
Confirm by NH_4HO to orig.
Dark Blue colour.
K_4 Fe Cy 6 to orig.
Red-brown pp.</td>
<td>White pp.
Bi.</td>
<td>Insoluble.
Cd.</td>
<td>Soluble.
Add KHO to orig.</td>
</tr>
<tr>
<td colspan="3"></td>
<td colspan="2">White p.p.
Sn (ic).
Confirm by Borax & Cu Bead test with orig.
No p.p.
As.
Confirm by Reinsch's Cu test with orig.</td>
<td></td>
<td></td>
</tr>
</table>

GROUP III.

If no p.p. with H_2S, add to the orig. NH_4Cl, NH_4HO and NH_4HS.

<table>
<tr>
<td colspan="2">BLACK P.P.
Collect p.p on filter, wash and dissolve in HCl and HNO_3; to this sol. add NH_4 HO. in excess.</td>
<td colspan="2">WHITE P.P.
Add NH_4HO in excess to orig.</td>
<td>GREENISH P.P.
Cr.
Confirm by KHO to orig.
Green p.p.
(soluble in ex of KHO.)</td>
<td>FLESH OR SALMON COLOURED P.P.
Mn.
Confirm by KHO to orig.
White p.p.
(Turning brown on shaking with the air.)</td>
</tr>
<tr>
<td rowspan="2">Red-brown p.p.
Fe.
To ascertain if Fe is in ferrous or ferric state, add to orig. K_4FeCy6.
Dark Blue p.p.
Fe (-ic).
Light Blue p.p.
Fe (-ous).
Confirm by $K_6Fe_2Cy_{12}$ to orig.
Dark Blue p.p.
Fe (-ous).
Dark Green colour.
Fe (-ic).</td>
<td colspan="2">No permanent p.p.
Add KHO to orig.</td>
<td>Insoluble.
Al.
Confirm by KHO to orig.
White p.p.
Soluble in excess of KHO.)</td>
<td>Soluble.
Zn.
Confirm by K_4FeCy6 to orig.
White p.p.</td>
</tr>
<tr>
<td>Red p.p.
Co.
Confirm by Borax bead.
(Blue colour.)</td>
<td>Green p.p.
Ni.
Confirm by Borax bead.
(Sherry colour.)</td>
</tr>
</table>

(*f.*)

GROUP IV.

If no p.p. in Group III, add to orig. NH_4Cl and $(NH_4)_2CO_3$.

If a p.p. falls, add to orig. $CaSO_4$ solution or very dil. H_2SO_4.

IMMEDIATE WHITE P.P.	WHITE P.P. FORMS ON STANDING FOR SOME TIME.	NO P.P. ON STANDING.
Ba. Confirm by K_2CrO_4 to orig. *Yellow p.p.* Flame reaction. *Green colour.*	Sr. Confirm by flame reaction. *Crimson colour.*	Ca. Confirm by NH_4HO and $(NH_4)_2C_2O_4$ to orig. *White p.p.*, insol. in $HC_2H_3O_2$. Sol. in HCl.

GROUP V.

If no p.p. in preceding groups, treat fresh portions of orig. sol. successively as follows :—

Add NH_4Cl, NH_4-HO and Na_2HPO_4	Add KHO and boil.	Add HCl, $PtCl_4$ and stir.	Dip a platinum wire in the orig. and insert in bunsen flame.	
			Yellow flame.	*Crimson flame.*
White granular p.p.	*Odour of Ammonia*,	*Yellow granular p-p.*		
Mg.	NH_4.	K.	Na.	Li.
		Confirm by shaking orig. with strong sol. of tartaric acid.		
		White granular p.p.		
		Confirm by flame reaction. *Lavender tint.*		

EXAMINATION of the Solution or of the Salt dissolved in water (boiling if necessary) for an acid :—

Test the solution with both blue and red litmus-paper. If it is acid, neutralize it carefully with NH_4HO before you examine it by Tables II., III., and IV. ; if it is alkaline, neutralize it carefully with dil. HNO_3 before you examine it by Tables III. and IV. There is no necessity to neutralize before examining by Table I.

TABLE I.

To orig. sol. add dil. HCl and heat ; notice if any gas or odour is evolved.

ODOURLESS GAS. (with effervescence)	ODOUR OF ROTTEN EGGS.	ODOUR OF BURNING SULPHUR.		ODOUR OF HYDROCYANIC ACID.	ODOUR OF ACETIC ACID.	WHITE JELLY FORMS.
Carbonate or *Bicarbonate.* Prove that the gas is CO_2 by its turning lime-water turbid. Add to orig. $MgSO_4$. *Carbonate.* P.p. *Bicarbonate.*— No p.p. Add to orig. $HgCl_2$. *Carbonate.*— Red p.p. *Bicarbonate.*— White p.p. (turning red.)	*Sulphide.* Confirm by the gas blackening $Pb_2C_2H_3O_2$.	Sol. remains clear. *Sulphite.* Confirm by treating orig. with Zn and HCl, when H_2S should be evolved.	Sol. becomes turbid. *Hyposulphite.* Confirm by adding $AgNO_3$ to orig. *White p.p. changing to yellow, orange, brown, and black.*	*Cyanide.* Confirm by adding to orig. the following reagents in the order mentioned — KHO, $FeSO_4$, Fe_2Cl_6 and HCl. *Dark blue p.p. of Prussian blue formed.*	*Acetate.* Confirm by adding to orig. alcohol and H_2SO_4 and boiling. *Odour of Acetic Ether.*	*Silicate.*

TABLE II.

SECTION I. If no reaction occurs in Table I. add to orig. $Ba2NO_3$. If a p.p. falls, add to it strong HCl.		SECTION II. Add to orig. (previously neutralised with NH_4HO if acid) $CaCl_2$. If a p.p. falls add to it strong $HC_2H_3O_2$.	
INSOLUBLE.	SOLUBLE.	INSOLUBLE.	SOLUBLE.
Sulphate.	Pass on to Section II.	*Oxalate.* Confirm by adding to this p.p. HCl which should dissolve it.	Pass on to Table III.

If no react

CINNAMON
P.I

Benz

Confirm by
orig. HCl w
give a w
soluble on
with Ether.





TABLE IV.

If no reaction occurs in previous tables add to orig. (rendered faintly acid with dil. HNO_3) Fe_2Cl_6.

CINNAMON-COLOURED P.P.	DARK BLUE P P.	DARK-GREENISH COLOUR.
Benzoate.	*Ferrocyanide.*	*Ferricyanide.*
Confirm by adding to orig. HCl which should give a white p.p. soluble on agitating with Ether.	Confirm by $CuSO_4$ to orig.	Confirm by $FeSO_4$ to orig.
	Brick-red p.p.	*Dark-blue p.p.*

TABLE V.

If no reaction occurs in previous tables add to orig. a drop or two of Sol. of Indigo Sulphate, and then strong H_2SO_4. If the colour of the Indigo is discharged the presence of a *nitrate* or *chlorate* is indicated. To ascertain which, add to orig. Cu turnings, strong H_2SO_4 and warm.

GAS EVOLVED, TURNING REDDISH-BROWN IN THE AIR.	NO ACTION.
Nitrate.	*Chlorate.*
Confirm by adding a crystal or two of $FeSO_4$ & strong H_2SO_4 to orig.	
Dark colour.	

ADDITIONAL HINTS.

I. If the orig. solution is strongly alkaline, and carbonates are absent, the presence of an alkali such as ammonia, potash, soda, or lime is indicated. Ammonia would be detected by its smell, the other alkalies by a brown p.p. on addition of $AgNO_3$.

II. If the salt is insoluble in boiling water, attempts should be made to dissolve it in HCl. If it dissolves without effervescence, the absence of a carbonate is indicated. To prove an oxide, since the metal has been previously detected, the physical and chemical properties of the oxide of that metal must be borne in mind and searched for; a few oxides, such as oxide of mercury. black oxide of manganese and peroxide of lead, evolve oxygen on heating; litharge is of a characteristic yellow colour; oxide of bismuth of a lemon colour; oxide of copper, black, forming with acids a green solution; oxide of antimony a buff colour, dissolving when boiled with cream of tartar and water; ferric oxide a reddish-brown colour; oxide of zinc a white colour, turning yellow when heated, but becoming white again on cooling.

III. The following are some of the reactions by which some of the more commonly occurring bodies, insoluble in HCl, may be recognized :—

Calomel by its turning black when treated with alkalies, and by its volatility.

Mercuric Iodide by its scarlet colour, and by its turning yellow on heating and scarlet again when the yellow modification is pressed.

Mercurous Iodide by its dirty-green colour and by its yielding some yellow and scarlet mercuric iodide when heated in a dry tube.

Mercurous Oxide by its black colour, by its evolving oxygen and by its yielding a sublimate of metallic mercury on heating.

Oxide of Silver by its brown colour and by its evolving oxygen when heated, the metal silver being left.

Sulphur by its yellow colour and by the peculiar odour when burnt.

Charcoal by its black colour, by its deflagrating when heated with KNO_3, and by its evolving SO_2 when boiled with strong H_2SO_4.

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